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(54) Optical switch

(57) Apparatus for deflecting a light beam comprises a dielectric liquid 9 contained in an enclosure 2, the walls of the enclosure being made of glass. The light beam 10 is incident on one wall of the enclosure 2, and the dielectric liquid 9 may be moved relative to the position of incidence of the light beam in one direction by means of capillary action and in the other direction by means of electrodes 7 and 8. The position of the dielectric liquid 9 determines whether the light beam 10 passes through the enclosure 2 undeflected, or whether it is deflected onto another path as a result of total internal reflection. Amplitude modulation can be produced by deflecting only part of a beam.

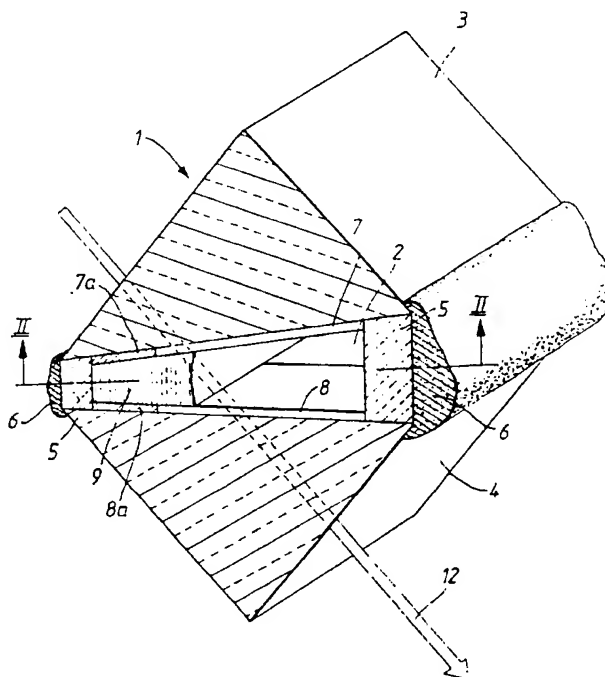


Fig. 1.

The drawing(s) originally filed was (were) informal and the print here reproduced is taken from a later filed formal copy.

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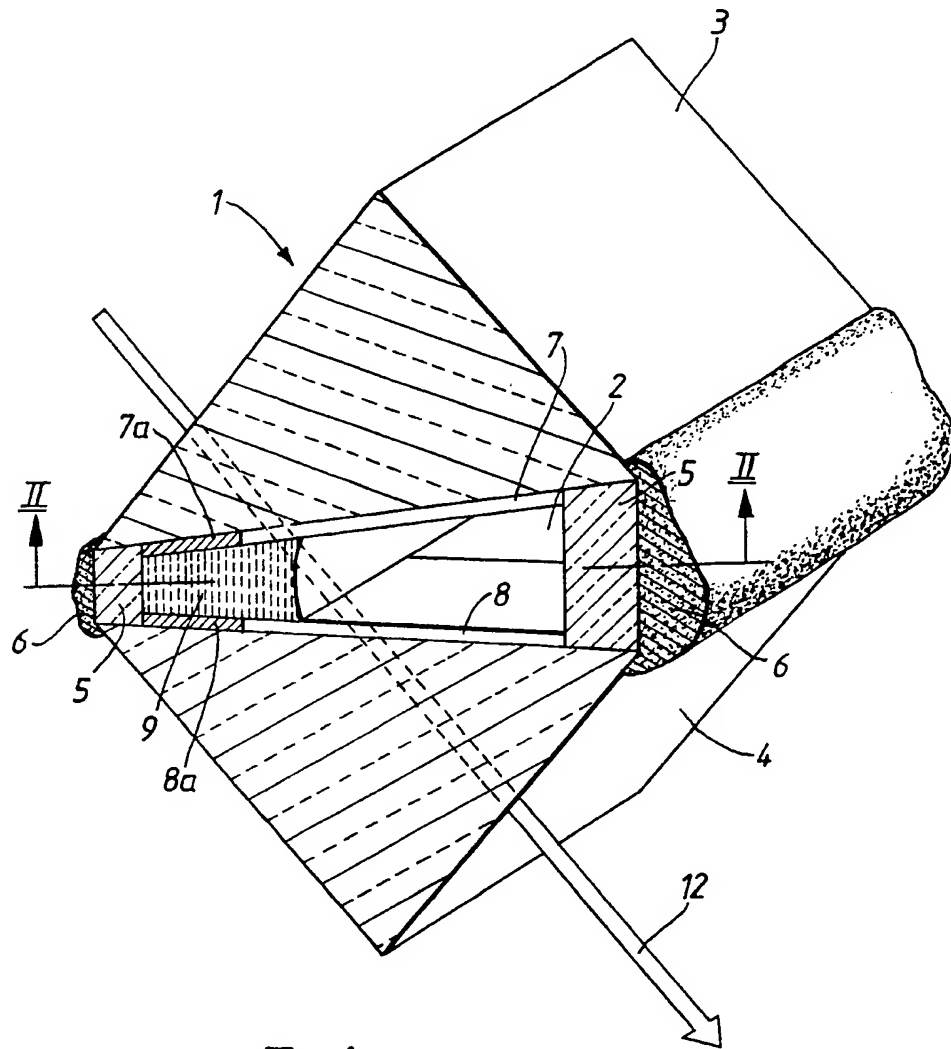


FIG. 1.

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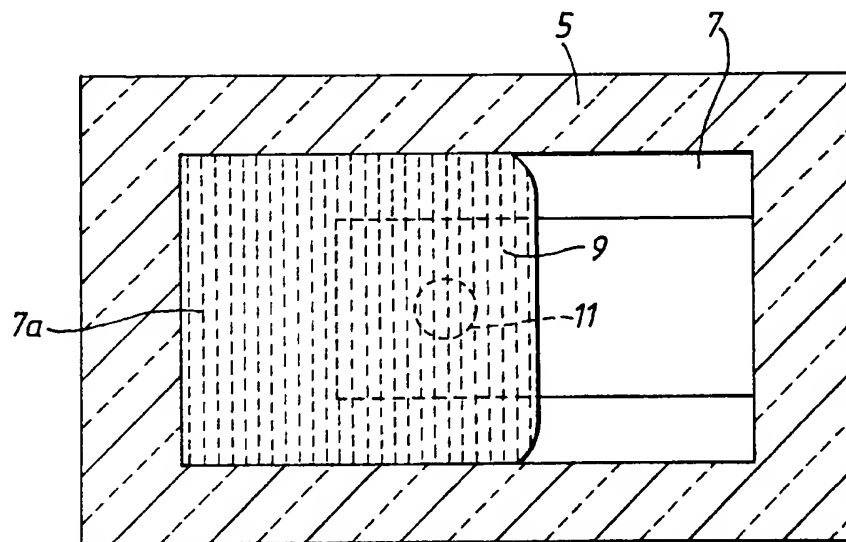


FIG. 2.

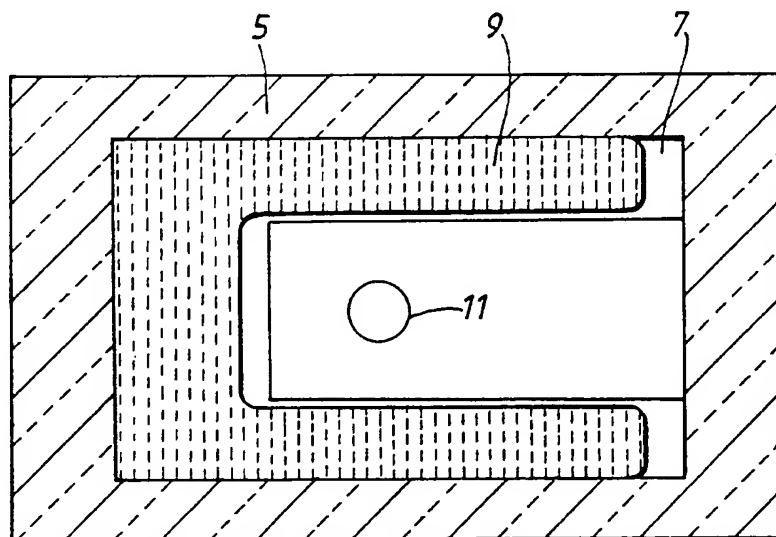


FIG. 4.

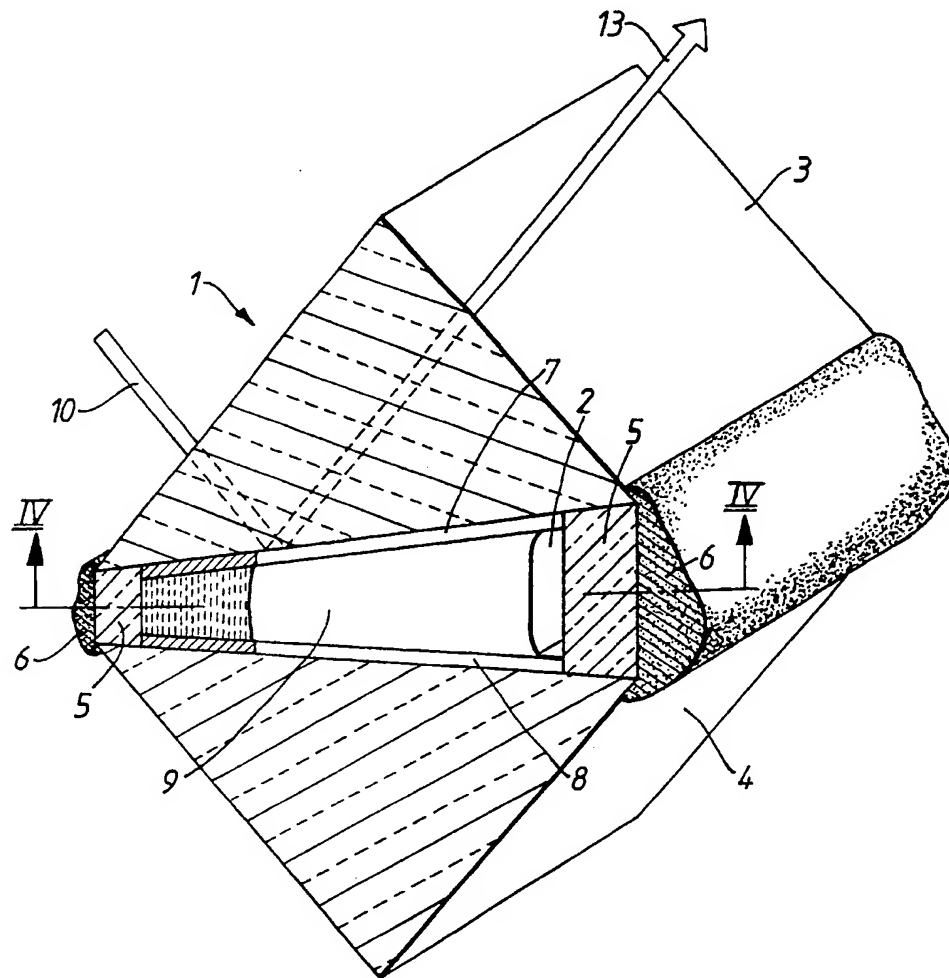


FIG. 3.

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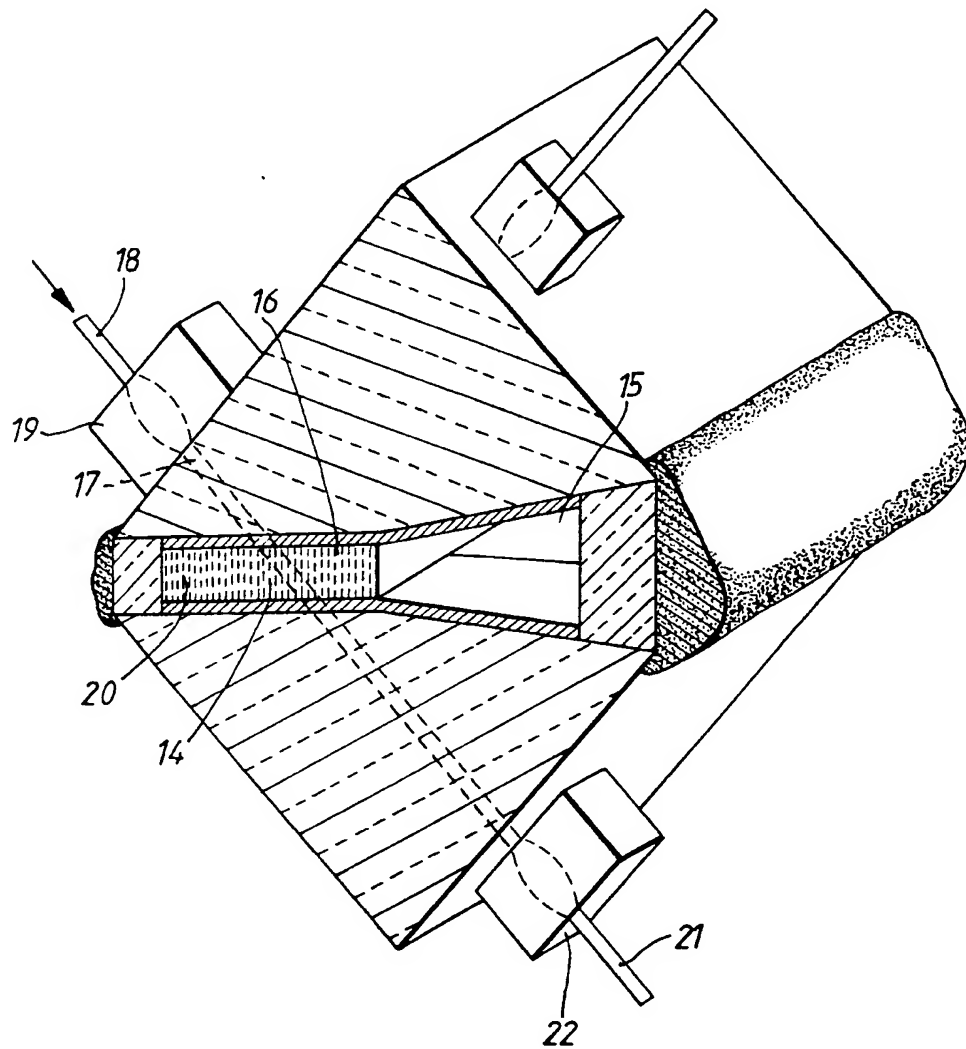


FIG. 5.

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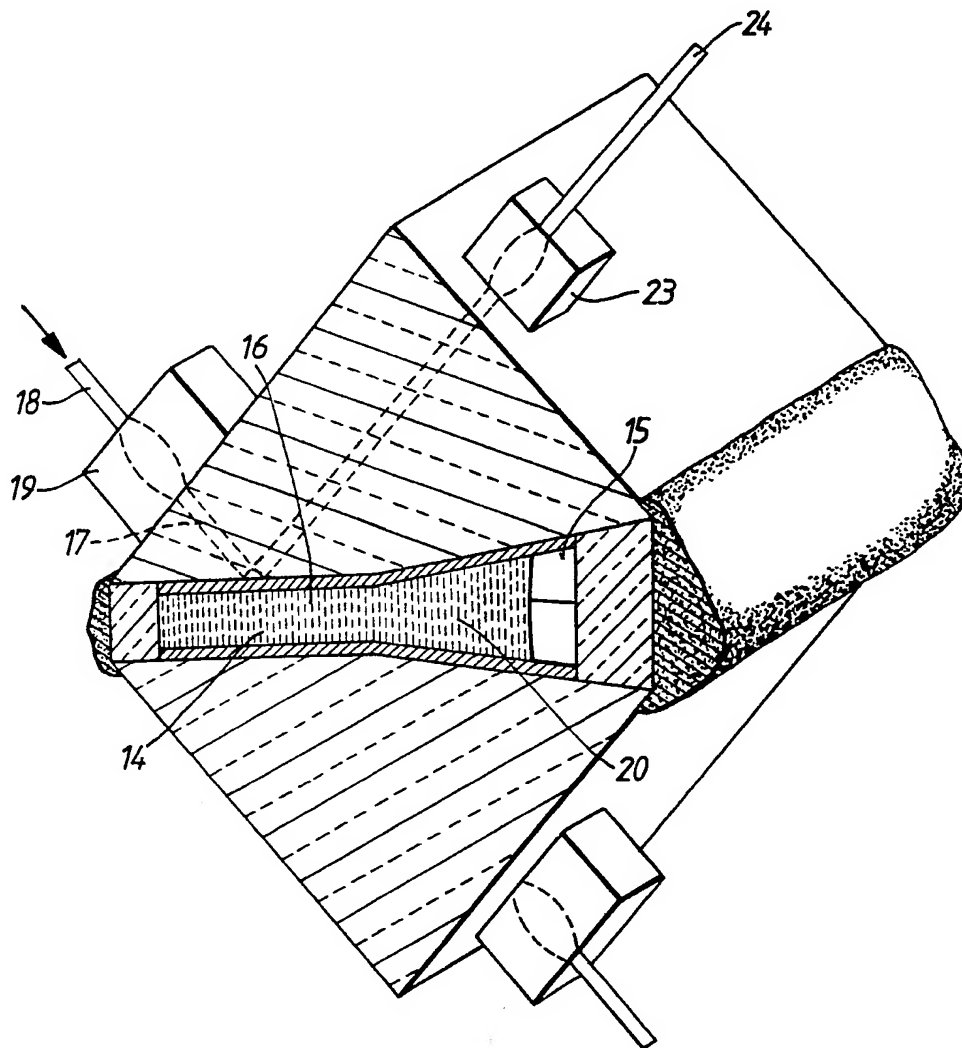


FIG. 6.

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Apparatus for Modifying a Light Beam

This invention relates to apparatus for modifying a light beam, and more particularly, but not exclusively, to an optical switch.

5 In a known apparatus for modifying a light beam, the beam is directed onto the surface of a mirror, which causes the beam to be deflected at a particular angle. The direction in which the beam is deflected may be altered by mechanically moving the mirror, thus altering the angle of incidence of the beam.

10 It is possible, using such an arrangement, to direct a beam of light to an output port, and then to switch it to any other of a plurality of output ports by mechanically moving a mirror.

15 The main disadvantage of this known apparatus is that if the mirror is subject to external forces such as vibration, the moving parts may move relative to each other, and re-adjustment may be necessary. Also, the moving parts necessary to alter the position of the mirror will wear out with use, and will have to be replaced  
20 periodically. The present invention seeks to overcome these problems.

The invention provides apparatus for modifying a light beam comprising: dielectric liquid contained in an enclosure configured such that capillary action is  
25 arranged to move liquid within the enclosure from a first

position to a second position within the enclosure; and means for moving the liquid from the second position to the first position, the arrangement being such that when the liquid is at the second position the light beam is  
5 incident on it, and when it is at the first position the light beam is not so incident, whereby the light beam is modified.

It should be noted that in this specification the term "light" should be interpreted as including infra-red  
10 and ultra-violet radiation as well as visible radiation.

The light beam could be modified, for example, such that it is switched from one path to another. In another embodiment of the invention the modification could be one of amplitude modulation, by arranging that some of the  
15 beam is deflected while the remainder continues along its original path.

Capillary action is the movement of liquid within a container which occurs because of its internal configuration. There is a force associated with an open  
20 surface of a liquid within a container which is dependent on the surface tension of the liquid, and also on the length of the perimeter of the open surface which is in contact with the container. This force acts in a direction away from the body of the liquid and normal to  
25 the open surface, and is inversely proportional to the length of the perimeter. Where the liquid within the container has two open surfaces, there is a force



associated with each of the surfaces. If one of the surfaces is of smaller area than the other, and is sufficiently small that the number of liquid molecules in contact with the container at the perimeter is a  
5 significant percentage of the molecules at the surface, there is a net force acting away from the body of the liquid at the smaller perimeter. This causes liquid to be drawn through the container to give capillary action. Thus, in apparatus in accordance with the invention, the  
10 configuration of the enclosure is chosen such that, when the liquid has two open surfaces, one of them has a shorter perimeter than the other, and it tends to move through capillary action to the first position.

Apparatus in accordance with the invention requires  
15 that the liquid be actively urged in one direction only, enabling a particularly simple and convenient arrangement to be used.

By using capillary action to move the dielectric liquid, it is possible to employ a simple electrode  
20 arrangement, for moving the liquid in the opposite direction, in which the light beam is not intercepted by an electrode. This gives easier index matching and thus enables losses to be reduced, compared to an arrangement in which light must be transmitted through an electrode.

25 Advantageously, first and second perimeters around the surface of the enclosure located at respective first and second locations along the direction of liquid flow

have different lengths, the perimeters being normal to the said direction. Capillary action may therefore be achieved by arranging that the cross-sectional area of the enclosure itself is non-uniform along the direction of liquid flow. Alternatively, the interior surface of the enclosure may be of a constant cross-sectional area in the direction of liquid flow, and inserts included within the enclosure to vary the cross-sectional area presented to the open surfaces of the liquid.

10 In one embodiment of the invention, the enclosure comprises two non-parallel planar facing surfaces. The perimeter and cross-sectional area of the enclosure may therefore be arranged to vary in a uniform manner in the direction of liquid flow.

15 Preferably, a portion of the enclosure is of constant perimeter and cross-sectional area normal to the direction of liquid flow. This configuration is particularly advantageous when a collimated light beam is employed. Collimation may be achieved using a graded refractive index lens, and refocussing of the light beam after it has been modified may also be obtained using a similar lens. Such lenses are typically used when light is guided along part of its path by optical fibres. By arranging that a portion of the enclosure is of constant perimeter and cross-sectional area in the direction of liquid flow, losses due to angular mis-match, which occurs when graded refractive index lenses are used, are reduced.

Preferably, the refractive index of the liquid is substantially the same as that of the enclosure, so that when the liquid is in the second position, and the light beam is incident on it, the light will pass through the liquid substantially unmodified.

Advantageously, a fluid, which fills the remainder of the volume not occupied by the liquid, has a refractive index which is greater than that of the enclosure. When the liquid is in the first position, light incident on the enclosure is incident on an interface between the enclosure and the fluid. The light undergoes total internal reflection at this interface because of the relative refractive indices of the enclosure and the fluid. Depending on the position of the liquid, light incident on the enclosure may be arranged to be reflected or to pass through the enclosure.

Preferably, the walls of the enclosure are made of glass, and comprise a prism through which the light beam is arranged to be transmitted.

Preferably, the means for moving the liquid from the second position to the first position is an electrode arrangement arranged to apply an electric field across the enclosure. When a potential difference is applied between electrodes of the electrode arrangement, if a portion of the liquid near to the electrodes lies within an electric field of sufficient magnitude, a force is exerted on it which causes it to move towards the electrodes. This

effect may be termed a Maxwell-Faraday effect. If a field of appropriate strength is applied, liquid moves towards the high field region until it is either all contained within a part of the volume of the enclosure between the electrodes, or, if the volume of the liquid is greater than that between the electrodes, as much of it as possible is located within the volume between the electrodes. The liquid may be moved from the first position to the second position by capillary action due to the configuration of the enclosure, and may be returned to the first position from the second position as a result of the electric field applied by the electrodes.

Preferably, the electrode arrangement is such that the light beam is not incident thereon. By positioning the electrodes so that they are not in the optical path of the beam, losses due to a mis-match of refractive indices are avoided. If the electrodes were positioned in the optical path of the beam, the beam would pass through interfaces between the electrodes and the enclosure, and the electrodes and either the dielectric liquid, or the fluid contained in the enclosure. At such interfaces there would be a mismatch of refractive indices, causing the light beam to be partially reflected. This would result in a loss of intensity in the light beam which is undesirable. Preferably, the electrode arrangement comprises first and second electrodes located on facing surfaces of the enclosure and substantially planar and U-

shaped.

According to a feature of the present invention there is provided optical switching apparatus comprising apparatus in accordance with the invention arranged such  
5 that the light beam is switched from one path to another depending on the position of the liquid.

Embodiments of the invention will now be described by way of example only, with reference to the following drawings in which:

10 Figure 1 is a schematic part sectional view of an optical switch in accordance with the invention, showing the switch in the state when no electric field is applied;

Figure 2 is a transverse section along the line II-II of Figure 1;

15 Figure 3 is a schematic part sectional view of the optical switch of Figure 1, showing the switch in the state when an electric field is applied;

Figure 4 is a transverse section along the line IV-IV of Figure 3; and

20 Figure 5 is another optical switch in accordance with the invention.

With reference to Figures 1 and 2, an optical switch 1 in accordance with the invention comprises an enclosure 2 which is substantially wedge-shaped in section as shown,  
25 being defined by the facing surfaces of two glass prisms 3 and 4 and a spacer 5 located between them. The enclosure 2 is about 12 mm in length, 6 mm wide and its thickness

varies from about 12  $\mu\text{m}$  at its thin end to 50  $\mu\text{m}$  at its other end. The spacer 5 may be, for example, of Mylar (trade mark). Epoxy resin 6 holds the prisms 3 and 4 and spacer 5 in position to provide a wholly sealed cavity.

5 Gold electrodes 7 and 8 are laid down on the facing surfaces of prisms 3 and 4 respectively. The electrodes 7 and 8 are substantially U-shaped, as more clearly shown in Figure 2, and are arranged with their cross pieces 7a and 8a at that end of the enclosure 2 at which the facing  
10 surfaces of the prisms 3 and 4 are closest together. Dielectric liquid 9 partially fills the enclosure 2 and in this embodiment is 93% benzonitrile and 7% isopropyl alcohol and has a refractive index of about 5.2. The remainder of the enclosure 2 is filled with air.

15 During operation of the switch, a collimated light beam 10 is directed through one of the glass prisms 3 and is incident at the interface between the prism 3 and the enclosure 2 at a position indicated at 11 between the arms of the U-shaped electrode 7.

20 Figures 1 and 2 illustrate the optical switch 1 and its effect on the light beam 10 when no field is applied between the electrodes 7 and 8. As there is no field present, the dielectric liquid 9 is located at the end of the enclosure 2 where the facing surfaces of the prisms 3  
25 and 4 are closest together because of capillary action. As the dielectric liquid 9 has a refractive index which is substantially the same as that of the glass of the prisms

3 and 4, light incident on the boundaries between the prism surfaces and the dielectric liquid 9 passes straight through the device and emerges along a path 12 with little or no reflection.

5        With reference to Figures 3 and 4, when a potential difference is applied between the electrodes 7 and 8, the dielectric liquid 9 is attracted to the high field region between the electrodes 7 and 8. Thus the dielectric liquid 9 takes on substantially the same configuration as  
10 that of the electrodes 7 and 8, becoming U-shaped. The attractive force on the dielectric liquid 9 is not dependant on the polarity of the field, and a direct current or alternating current may be applied.

      When the beam of collimated light 10 is now incident  
15 at the interface between the prism 3 and the enclosure 2 at 11, it is not incident on any dielectric liquid 9 but on the air filling the remainder of the enclosure 2. As the refractive indices of glass and air are different, the light beam is deflected at the interface between the prism  
20 3 and enclosure 2 because of total internal reflection, and emerges from the device along a path 13 which is at 90 degrees with respect to the straight through path which the light follows when no field is applied between the electrodes.

25        If the electric field is then removed, the dielectric liquid 9 returns to the position shown in Figure 1 as a result of capillary action because of the shape of the

enclosure and its changing cross-section along the direction of liquid flow.

With reference to Figure 5, another optical switch in accordance with the invention comprises an enclosure 14 which consists of a first portion 15 which has a wedge-shaped section such that the cross-sectional area decreases in a uniform manner from right to left as shown, and a second portion 16 which is of substantially constant cross-sectional area. In this embodiment, the light beam 17 is arranged to be incident on the enclosure 14 at the second portion 16 which is of uniform cross-sectional area. The light beam originates from an optical fibre 18 and is collimated by a graded refractive index lens 19 for transmission through the glass to the second portion 16. In the state of the switch shown in Figure 5, no electric field is present and the dielectric liquid 20 occupies substantially all the volume of the uniform cross-sectional area portion 16. The light beam 17 is incident on the dielectric liquid 20 and passes in a straight path to an output optical fibre 21 onto which it is focused by a graded refractive index lens 22.

Figure 6 illustrates the switch of Figure 5 when an electric field is present between the electrodes, which are U-shaped electrodes similar to those of the optical switch shown in Figure 1. The light beam from the optical fibre 18 and lens 19 undergoes total internal reflection at the interface between the glass and air and is directed



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to another graded refractive index lens 23 where it is focused onto an output optical fibre 24.

CLAIMS

1. Apparatus for modifying a light beam comprising: a dielectric liquid contained in an enclosure configured such that capillary action is arranged to move the liquid from a first position to a second position within the  
5 enclosure; and means for moving the liquid from the second position to the first position, the arrangement being such that when the liquid is at the second position the light beam is incident on it, and when it is at the first position the light beam is not so incident, whereby the  
10 light beam is modified.
2. Apparatus as claimed in claim 1 and wherein first and second perimeters around the interior surface of the enclosure, located at respective first and second locations along the direction of liquid flow have  
15 different lengths, the perimeters being normal to the said direction.
3. Apparatus as claimed in claim 2 and wherein a portion of the enclosure is of constant perimeter and cross-sectional area in the direction of liquid flow.
- 20 4. Apparatus as claimed in claim 1, 2 or 3 and wherein the enclosure comprises two non-parallel planar facing surfaces.
5. Apparatus as claimed in any preceding claim and including a light guide along which the light beam is  
25 arranged to be transmitted.
6. Apparatus as claimed in any preceding claim and

wherein the light beam is arranged to be transmitted through material of walls of the enclosure and the refractive index of the liquid is substantially the same as that of the material.

5       7.   Apparatus as claimed in any preceding claim and wherein fluid occupying that part of the enclosure not occupied by the liquid has a refractive index greater than that of the material of walls of the enclosure.

8.   Apparatus according to any claim and wherein the  
10   walls of the enclosure are of glass.

9.   Apparatus as claimed in claim 8 and wherein the walls comprise a prism through which the light beam is arranged to be transmitted.

10.   Apparatus as claimed in any preceding claim and  
15   wherein the first means is an electrode arrangement arranged to apply an electric field across the enclosure.

11.   Apparatus as claimed in claim 10 and wherein the electrode arrangement is such that the light beam is not incident thereon.

20   12.   Apparatus as claimed in claim 10 or 11 and wherein the electrode arrangement comprises first and second electrodes located on facing surfaces of the enclosure and are substantially planar and U-shaped.

13.   Optical switching apparatus comprising apparatus as  
25   claimed in any preceding claim arranged such that the light beam is switched from one path to another depending on the position of the liquid.

14. Apparatus substantially as illustrated in and described with reference to the accompanying drawings.